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## PRESSURE DROP CHARACTERISTICS FOR SHUTTLE ORBITER THERMAL PROTECTION SYSTEM COMPONENTS: HIGH DENSITY TILE, LOW DENSITY TILE, DENSIFIED LOW DENSITY TILE, AND STRAIN ISOLATION PAD

Pierce L. Lawing and Donna M. Nystrom

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Langley Research Center
Hampton, Virginia 23665

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NASA Langley Research Center

## SUMMARY

Sudden external pressure changes during the Space Shuttle Orbiter ascent and descent will impose pressure loads on the tile system due to air trapped within and beneath the tiles. An example of such a pressure change is the movement of the normal shock during the transonic portion of the flight. In order to quantify these pressure loads it is necessary to perform a venting analysis to determine how quickly the internal pressures will change. In turn, a venting analysis requires pressure drop characteristics of the tile system components. Pressure drop tests have been conducted on available samples of low and high density tile, densified low density tile, and strain isolation pad. The results are presented in terms of pressure drop, material thickness and volume flow rate. Although the test apparatus was only capable of a small part of the range of conditions to be encountered in flight, the data serve to determine the type of flow characteristics to be expected for each material type tested.

## INTRODUCTION

The determination of the heating and forces on components of the Space Shuttle Orbiter thermal protection system requires a knowledge of the equilibrium

and dynamic flow of air internal to the components. For instance, an equilibrium flow of air will take place through the system in response to an external pressure gradient, such as might exist in the neighborhood of a leading edge. The passage of a transonic shock may occur rapidly and result in dynamic changes as air rushes in or out of the porous interior of the insulating tiles, their strain isolators, and the filler bars which fill gaps between the tiles. Further information on the thermal protection system may be found in reference 1.

There are a large number of individual tiles which when coupled with varying geometry, different gap spacing, filler bars, strain isolation pad thicknesses and a wide range of flow conditions, leads to a complex array of venting and flow-through conditions to consider. A computerized analysis technique would be very desirable to calculate internal flows and associated heating, pressure distributions and loads. Primary requirements in developing such an analysis technique are materials data, pressure drop characteristics in particular, and known solutions with which to test and develop the technique.

A literature search quickly reveals that there is no trustworthy analytical approach available for predicting pressure drop parameters for these materials, and that known solutions vary by orders of magnitude. Summations of the literature may be found in references 2, 3 and 4. Accordingly, within the constraints of time, equipment and available test samples, an experimental program was undertaken to determine pressure drop characteristics of tile and strain isolation pad or SIP material. It is the purpose of this document to present these experimental results.

## Test Apparatus and Procedure

A commercial unit originally used to determine the porosity of parachute cloth was used for the present tests. The unit is a Frazier

Porosimeter manufactured by the Frazier Precision Instrument Company, 8913 Glenville Road, Silver Spring, MD, and its operation is depicted in the sketch shown in figure 1. A small centrifugal compressor draws air through the apparatus as shown. Volume flow rate is determined by means of a set of orifices, orifice calibration sheets supplied by the manufacturer, and a differential Merriam Red Oil manometer. The orifice calibration sheets supplied were for a 6.985 cm (2.75 in.) diameter circular opening at the test sample mounting flange, and a square opening 2.54 cm (1.0 in.) on a side. The orifice calibration data for one opening could be directly converted by the area ratio of the two openings, to agree with the orifice calibration data for the other opening, thus indicating that the calibration factors are not a strong function of the exact size and shape of the opening. Nevertheless, where possible, 6.985 cm diameter cylindrical samples were supplied for test, as shown in figure 1. There was not sufficient material available to prepare such a SIP sample and this material was tested in a single sheet as shown in figure 1. The flow exit is approximately 0.254 x 5.08 cm (0.1 x 2.0 in.) for an opening area of 1.29 $cm^2$ (0.2 $in.^2$).

Pressure drop across the sample is the difference between atmospheric pressure and the lower pressure in the chamber between the mounting flange and the calibrated orifice, as shown in figure 1. This pressure difference is also read by a Merriam Red Oil manometer referenced to atmospheric pressure.

To obtain pressure drop as a function of thickness, a cylinder of tile material was first tested for the full thickness of the tile sample

(with the exterior coating removed). Readings were taken over a range of volume flow rates and for several appropriately selected orifices. A disc was then sliced from the top of the cylinder and the readings repeated.

A primary difficulty in these tests was prevention of leaks past the sample being tested. To minimize this problem the tile samples were first coated with ordinary desk top rubber cement and then fitted to a cardboard collar. The sample and its collar were then coated several more times with at least 2-hour drying intervals between coats. Before testing, the collar was cemented to the brass mounting flange. The SIP sample was prepared by attaching cardboard to the SIP with double backed tape and then coating all of the exterior, except for the entrance and exit, with several coats of rubber cement. This package was then mounted in a collar in a manner similar to the tile samples (fig. 1). The SIP sample had a flow length or thickness of 9.52 cm (3.75 in.); no tests were made to determine flow characteristics as a function of thickness (flow length).

## RESULTS AND DISCUSSION

Pressure drop as a function of material thickness for the high density tile for selected constant values of volume flow rate is presented in figure 2. This particular tile sample was the thickest available and data were taken for six different values of thickness resulting in the largest amount of data for any one sample. As may be seen from figure 2, pressure drop is a linear function of the thickness for a constant volume flow rate. Figure 3 presents the data for this same sample as volume flow rate as a function of thickness for constant values of pressure drop. Figure 4 presents the data in terms of pressure drop as a function of volume flow rate for constant values of thickness. Figures 2, 3, and 4 have presented the data cast in different variables to illustrate the flow characteristics as a function of

each of the three variables. Figure 4 also presents the data for the low density tile at comparable values of material thickness. In addition to the obvious differences in flow resistances of the two tile types, this figure demonstrates that pressure drop is essentially linear with volume flow rate, a characteristic of low Reynolds number flows. At high Reynolds number, the pressure drop would be expected to vary as the volume flow rate squared.

Figure 5 repeats the data of figure 4 with the data from a sample of densified low density tile and the SIP sample shown for comparison. These materials also exhibit low Reynolds number behavior in that they have linear pressure drop characteristics as a function of volume flow rate. However, the densified tile pressure drop data, figure 6, no longer exhibits linear behavior with tile thickness due to the nonlinear increase in density as the bonding surface (zero thickness) is approached. On figure 6, this behavior is compared with both the low and high density tile data presented previously to indicate that the low density densified tile has pressure drop values roughly equivalent to the high density tile in the 1 to 3 cm thickness range. At thicknesses greater than the penetration of the densifying solution, the slope of the pressure drop curve can be expected to approach that of the untreated low density tile; this slope is included on figure 6 for reference purposes. Although the distribution of the densifying material is unknown, a speculative dotted line is included based on the approximate visual thickness of the densified layer (≈ .25 cm) and the supposition that for a fixed volume flow rate, the pressure drop must approach zero as the thickness approaches zero. The shape of the dotted line is further supported by the observations in appendix 11 of reference 1 where it is reported that the densifying material forms a dense crust about 0.5 mm thick with most of the material remaining within about 4 mm of the bonding surface. This

information is based on photomicrographs of a sample of densified tile different from the one tested in the present report, however the steep initial slope of the dotted line is consistant with the observed distribution of reference 1. Thus, with increasing thickness from the bonding surface, the pressure drop curve is expected to behave as indicated by the dotted line, pass through the available data points and proceed along, or at least become parallel to, the low density tile slope line.

## APPLICABILITY OF RESULTS

Obviously, the full range of variables discussed in the introduction have not been addressed in these tests. The particular problem that triggered the conduct of the present test was the loading due to the transient passage of a transonic shock wave during ascent. Presumably, room temperature is adequate for these tests. However, neither the pressure level or the transient nature of a passing shock have been simulated. At higher pressure drops, the associated higher volume flow rates, the low internal Reynolds number flow, which allows a linear relation between pressure drop and volume flow rate, may change. Thus extreme extrapolation of the present results may result in some error. The errors are, however, expected to be second order in nature. Also, the present tests were static in nature and a rapidly changing pressure may not provoke mass flow in the same manner as the steady pressures used in these tests. A final caution in applying these data is the limited number of samples some of which were cut from rejected or nonspecification materials.

## CONCLUSIONS

Volume rate of flow and associated pressure drop measurements have been made on samples from the interior of tiles and samples of strain

isolation pad. These materials are typical of those to be used in the Shuttle Orbiter thermal protection system and the measured quantities should serve for initial venting and flow through analysis.

Specific conslusions are as follows:

1. Material from the interior of a tile exhibits a linear pressure drop as a function of material thickness for a constant volume flow rate.

2. For a constant value of thickness, material from the tile interior has an approximately linear pressure drop with volume flow rate, displaying the characteristic expected for very low Reynolds number flows.

3. The strain isolation pad material has flow characteristics very similar to the material from the tile interior.

4. Pressure drop as a function of material thickness for densified tile is nonlinear as the bonding surface is approached for a constant volume flow rate.

References

1. "Orbiter TPS Strength Integrity Assessment." Battelle Columbus Laboratories, June 16, 1980. (Final Report)

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3. "American Institute of Physics Handbook." Office of Science Information Services National Science Foundation. McGraw-Hill Book Company, Inc.

4. "Viscous Fluid Flow," by Frank M. White (Professor of Mechanical and Ocean Engineering), University of Rhode Island, Kingston, Rhode Island, 1974.

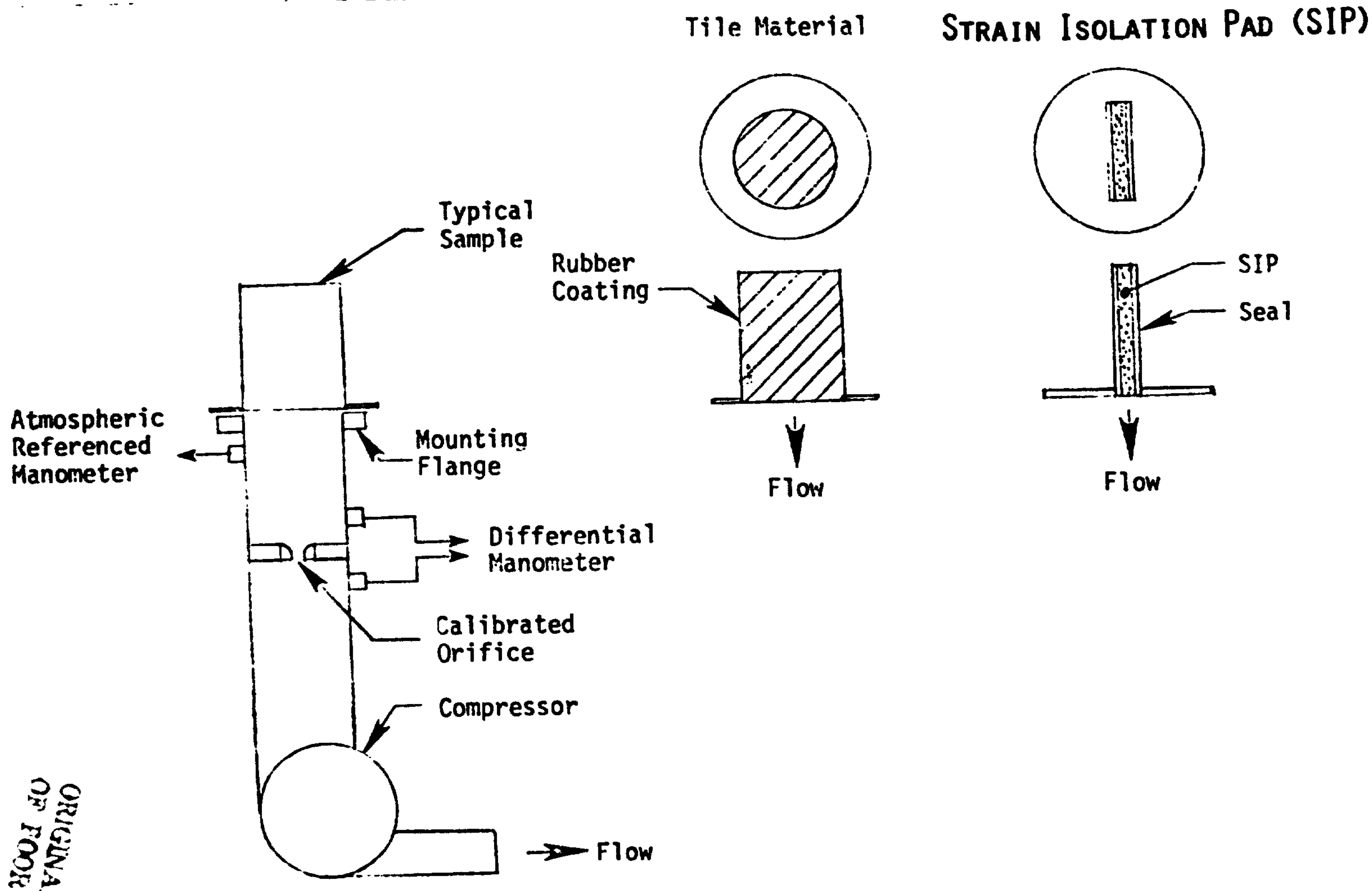


Figure 1.- Sketch of Frazier Porosimeter and typical test specimens.

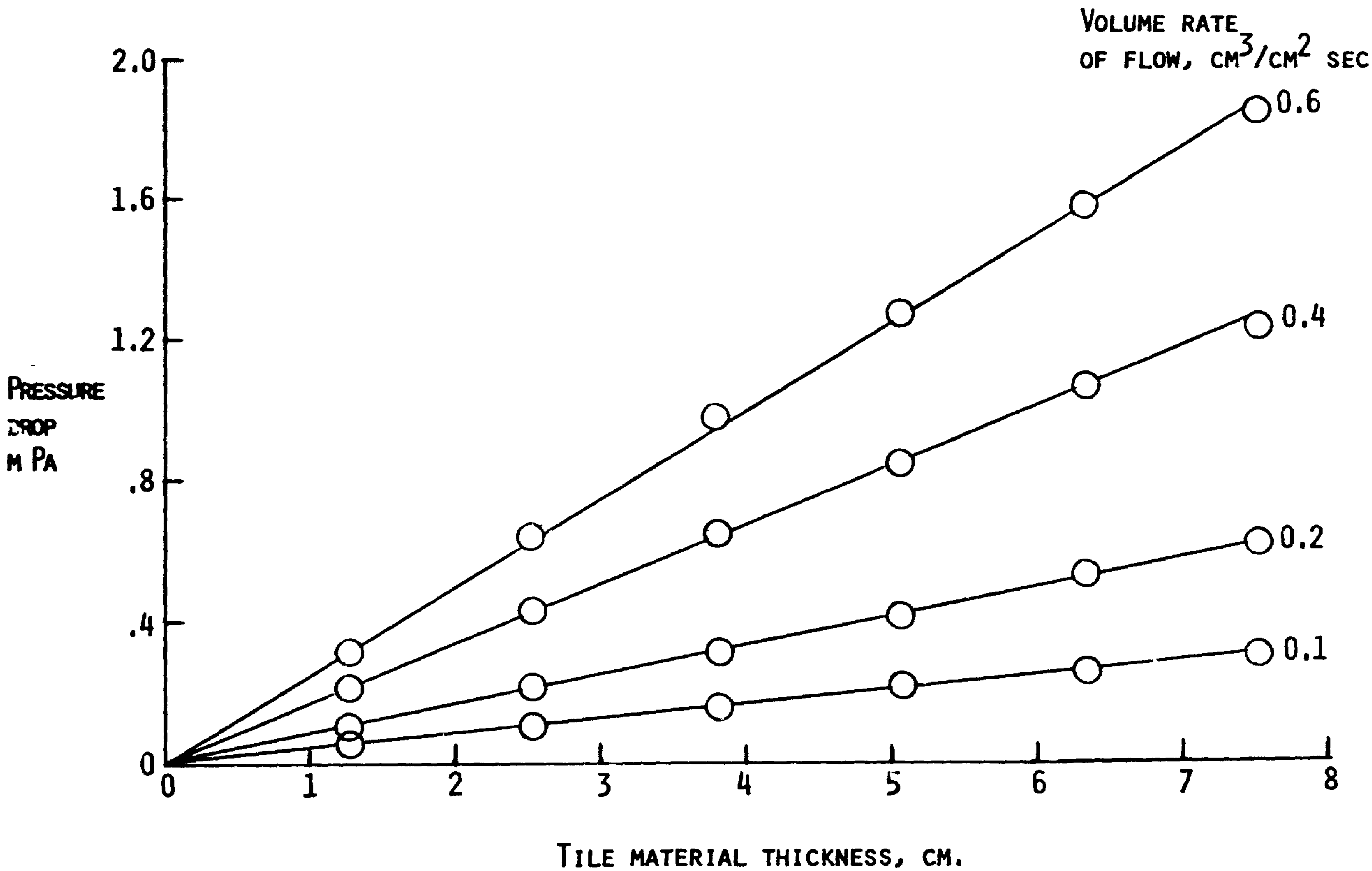


FIGURE 2.- PRESSURE DROP AS A FUNCTION OF THICKNESS AT CONSTANT RATES OF VOLUME FLOW FOR HIGH DENSITY TILE SAMPLE.

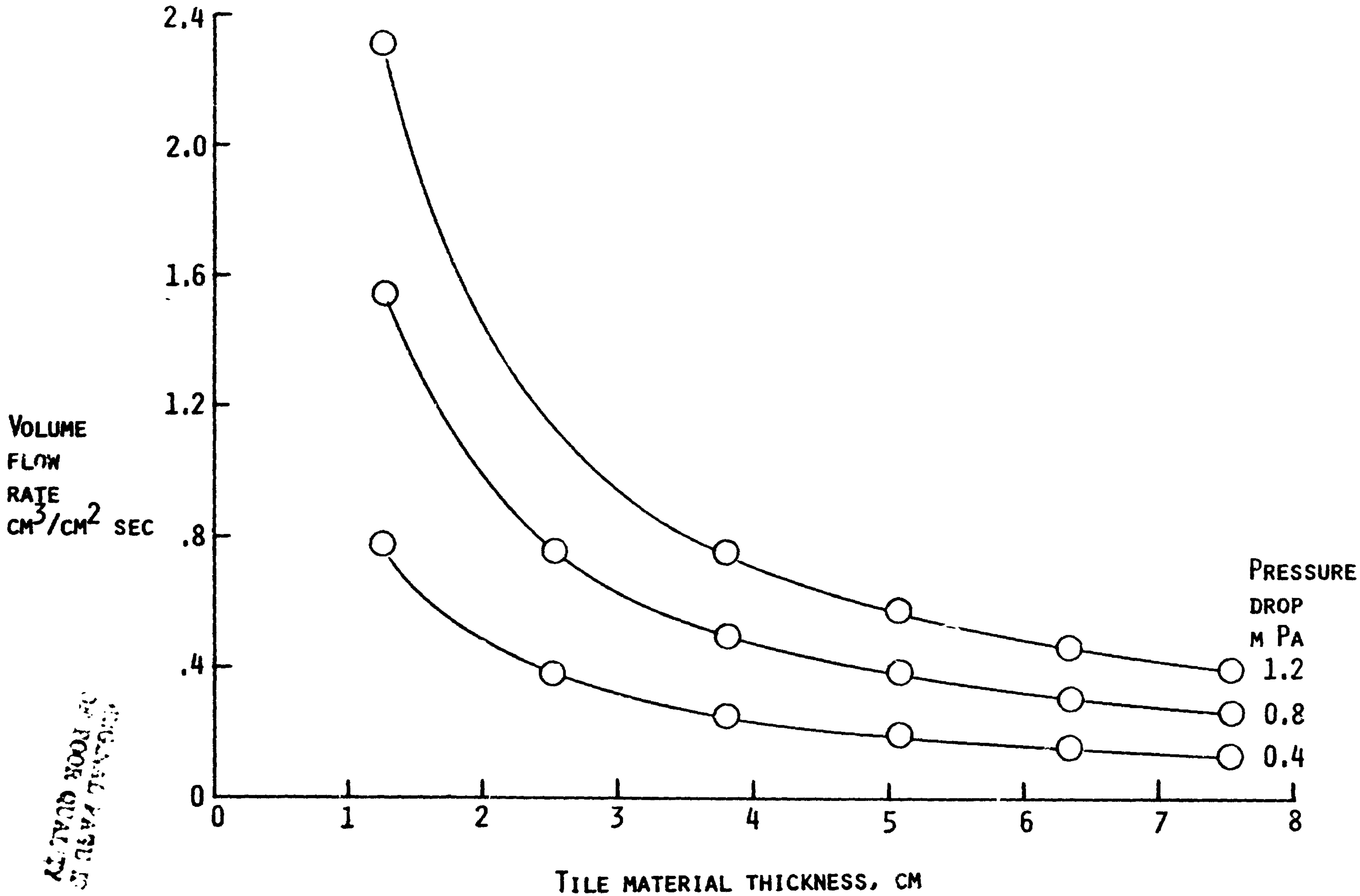




Figure 3.- Volume flow rate as a function of thickness for constant values of pressure drop; high density tile sample.

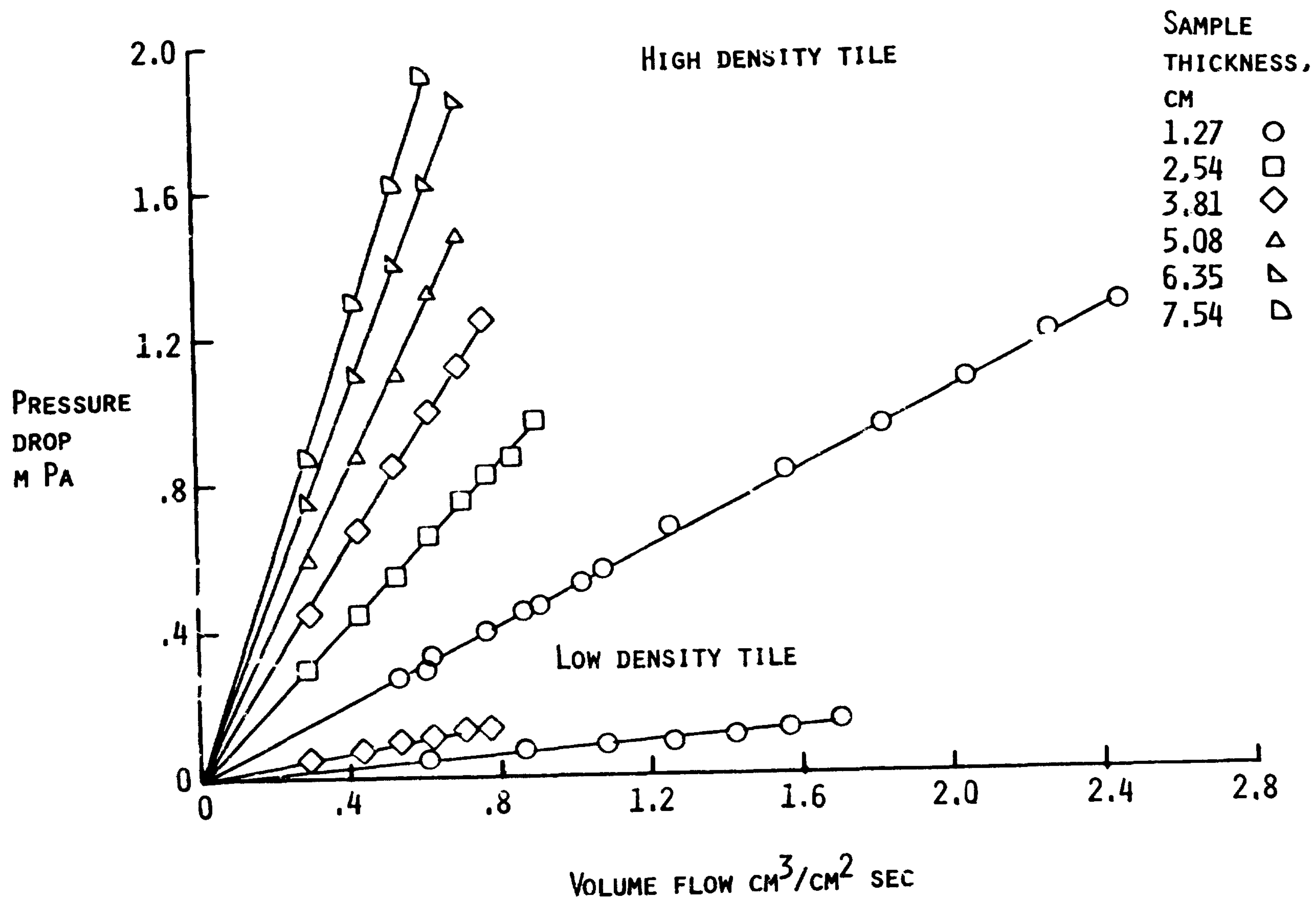


FIGURE 4.- PRESSURE DROP AS A FUNCTION OF VOLUME FLOW RATE FOR CONSTANT VALUES OF THICKNESS; HIGH AND LOW DENSITY TILE SAMPLES.

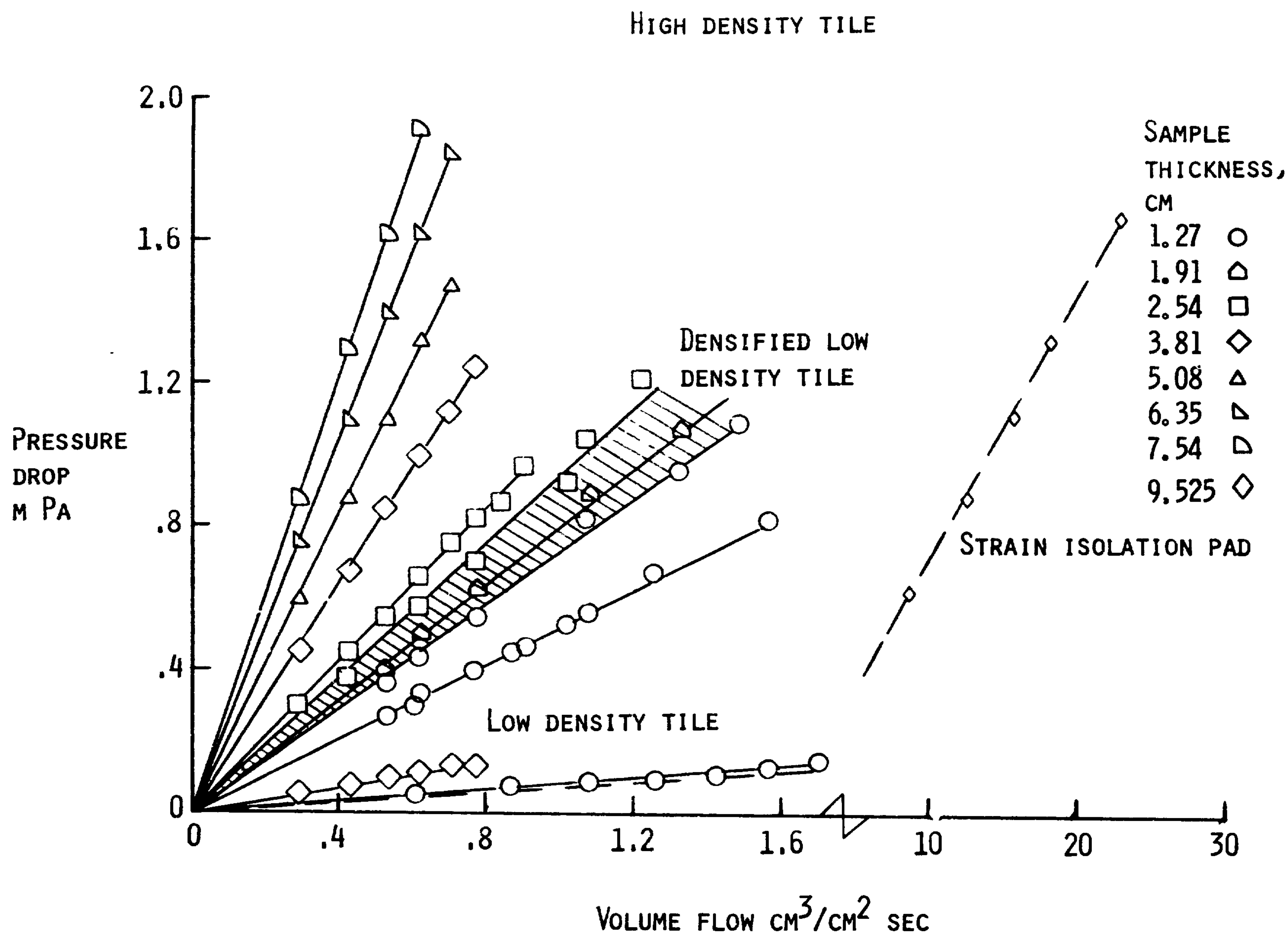


FIGURE 5.- REPEAT OF FIGURE 4 WITH OVERLAY OF DENSIFIED LOW DENSITY TILE AND STRAIN ISOLATION PAD DATA

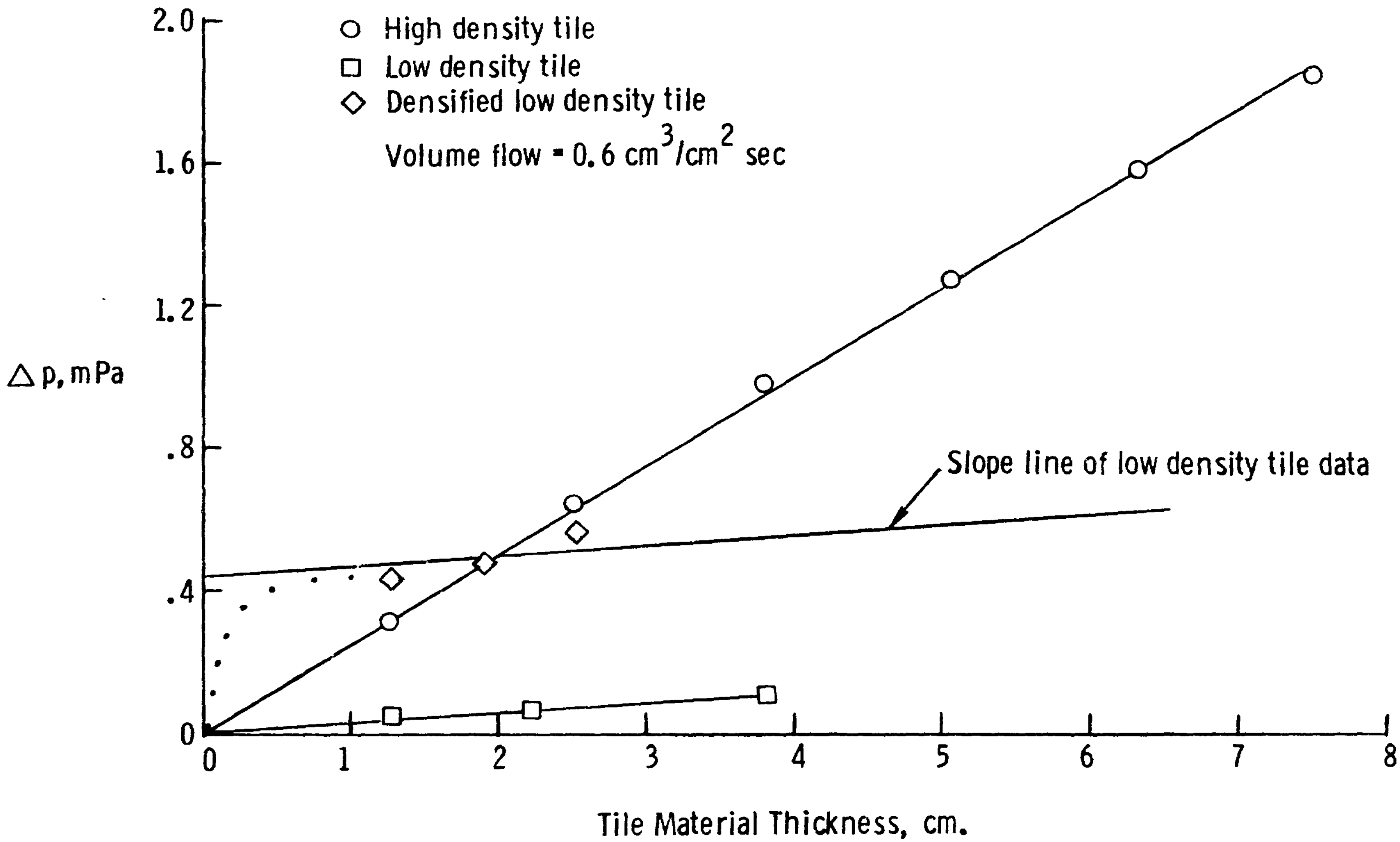


Figure 6.- Comparison of data for low and high density tile with densified low density tile.